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## Some aspects of prototyping oversized parts through PolyJet technology

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**Abstract.** The paper presented a series of experiments to improve the performance of rapid prototyping processes. The paper presents aspects regarding the realization of polymeric parts by PolyJet rapid prototyping technology. Achieving oversized parts on printers whose print size is small is subject to additional demand for the designer and the technology engineer who designs the printing strategy. Small parts segmentation is a solution, provided that after gluing the parts with adhesives recommended by the manufacturer, the general assembly acts as a one-piece piece – this is the ideal case. An acceptable solution is that the overall assembly has at least 70-80% of the properties of a part made up of a single piece. In the present work several sets of specimens were used for the experiment and they were joined together. Their properties were compared to one-piece specimens. Finally, the useful conclusions for designers and technologists are presented.

### 1. Introduction

PolyJet 3D type printers from Stratasys are affordable solutions used to deliver realistic 3D models through fast prototyping [1, 2]. PolyJet 3D printing technology enables the production of very precise parts, which can be functional or just used in project presentations, [3, 4].

Materials used for rapid prototyping are very varied: plastics (which are the most), metallic materials, rarer non-metallic materials, and very often materials such as wax, paper or rubber, [5-8]. Very often, PolyJet technology uses materials such as:

- individual basic resins;
- digital materials produced by combining two or more basic resins;
- polymeric materials that mimic polypropylene, ABS and other plastic materials;
- specialty materials for requirements like heat resistance or biocompatibility;
- materials such as the above, which can be combined into a single print job.

For example, a Stratasys 3D printer is ObJet30 Pro; this printer is desktop sized high-end rapid prototyping. The printer can use eight different types of materials, such as clear, high-temperature and simulated polypropylene [9, 10].



*PolyJet technology. Objet printers from Stratasys use PolyJet technology.* The pieces are printed on a polygonal printing technology using STL files, [11-13]. The printer jets up the layers of liquid photopolymer and solidifies them with UV light. The pieces thus obtained can be manipulated and used immediately. Similar to other printers, the Objet printer starts the printing operation by depositing several layers of wax support on the printing table. The layers are immediately solidified, [14-16]. Once the printing base has been made, the printhead begins to deposit the VeroWhitePlus material, which is a heavy ABS material, such as plastic. Also, if necessary, support material (wax type) is also required depending on the configuration of the part to be made. The printer continues to lay layer after layer (material plus wax) until printing is complete, [11].

The characteristics of the VeroWhitePlus FullCure 835 material are shown in tables 1, 2 and 3, [12].

**Table 1.** VeroWhitePlus FullCure 835 physical properties, [17].

Physical Properties		Test Method
Specific Gravity	1.17 - 1.18 g/cc	Polymerized; ASTM D792
Water Absorption	1.10 - 1.50 % , @Time 86400 sec	ASTM D570-98
Ash	0.230 - 0.260 %	USP281

**Table 2.** VeroWhitePlus FullCure 835 mechanical properties, [17].

Mechanical Properties		Test Method
Hardness, Rockwell M	73.0 - 76.0	
Hardness, Shore D	83.0 - 86.0	
Tensile Strength at Break	50.0 - 65.0 MPa	ASTM D638-03
Elongation at Break	10.0 - 25.0 %	ASTM D638-03
Modulus of Elasticity	2.00 - 3.00 GPa	ASTM D638-04
Flexural Strength	75.0 - 110 MPa	ASTM D790-03
Flexural Modulus	2.20 - 3.20 GPa	ASTM D790-04
Izod Impact, Notched	0.200 - 0.300 J/cm	ASTM D256-06

**Table 3.** VeroWhitePlus FullCure 835 thermal properties, [17].

Thermal Properties		Test Method
Deflection Temperature at 0.46 MPa (66 psi)	45.0 - 50.0 °C	ASTM D648-06
Deflection Temperature at 1.8 MPa (264 psi)	45.0 - 50.0 °C	ASTM D648-07
Glass Transition Temp, T <sub>g</sub>	52.0 - 54.0 °C	

The material presented above is rigid, opaque, offers hardness, dimensional stability, and allows detailed detail viewing of the piece obtained during rapid prototyping. In this paper the material VeroWhitePlus FullCure 835 was used, and the 3D PolyJet printing technology on a Stratasys Objet24 printer. The print layers were made in size of 28µm and the size of the print table was 240 mm x 200 mm x 150 mm [18].

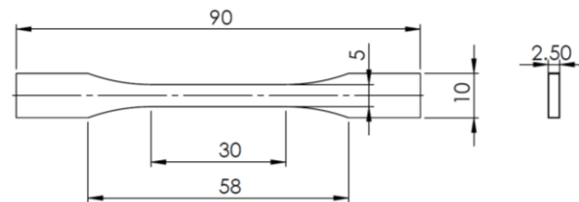
As can be seen, very often the useful size of the print table is not enough to produce pieces of size used in the construction of machines and appliances. For this reason, it is necessary to segment the piece and to bond these segments with special adhesives, [19].

Stratasys recommends the following types of adhesives. The types of adhesives most commonly used are known as cyanoacrylate. Cyanoacrylate is an acrylic resin that rapidly polymerizes in the presence of water. For instance, ALTECO ACE can also be used, [19-21].

Other types of adhesives for rigid parts: LOCTITE 401 is recommended for medium viscosity. Permabond Ultra Fast 792 can also be used with very fast cure time for general use. An indicated adhesive is also Al-fix - which uses the activator. It can also use Kleiberit 851.0, which is very easy to practice. For flexible parts, the Sico Met 8300 or Permabond Black Magic 737 is recommended, [20].

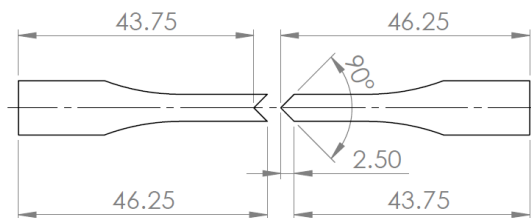
## 2. Making material tests and joining tests

In the paper we conducted two types of tests: a) material tests using standard sizes for plastic specimens, and b) tests for joining test specimens using Stratasys-specified adhesives.



**Figure 1.** Test specimens according ISO 527-2 2012E, type 1BA, [22, 23].

The dimensions for specimens were tested according to ISO 527-2 2012 (E), Annex A, type 1BA. The drawing of the specimen is shown in figure 1.



**Figure 2.** Specimen's dimensions for joining [22, 23].



**Figure 3.** Test specimens for joining tests (VeroWhitePlus FullCure 835).

All the specimens were made physically from VeroWhitePlus FullCure 835 material. Figure 2 shows the dimensions of the specimens used to test the joining. Figure 3 shows test specimens for joining tests made of VeroWhitePlus FullCure 835 material.



**Figure 4.** Universal testing machine, load cell of 5kN, Zwick / Roell Z005.



**Figure 5.** ObJet 24 3D printer produced by Stratasys.

Figure 4 shows the traction test of test specimens on Zwick / Roell Z005, load cell of 5 kN. This machine, (shown in figure 4), was used for all types of polymeric material tests presented in this paper.

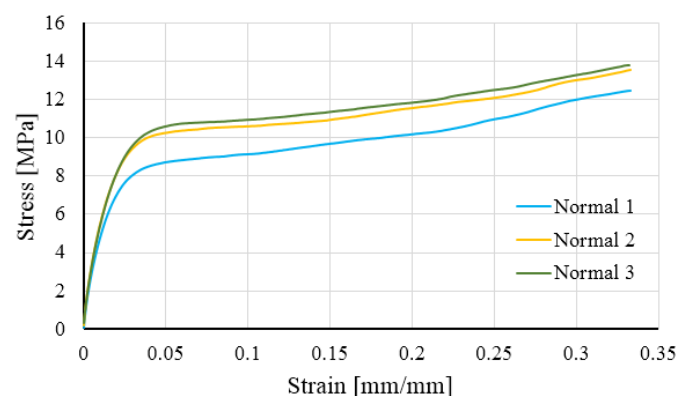
All samples (specimens) were performed on a 3D ObJet 24 printer produced by Stratasys presented in figure 5. Following traction tests, samples were obtained as shown in figure 6. It was intended to find a solution for joining complex pieces that can not be made (3D print) in one piece.



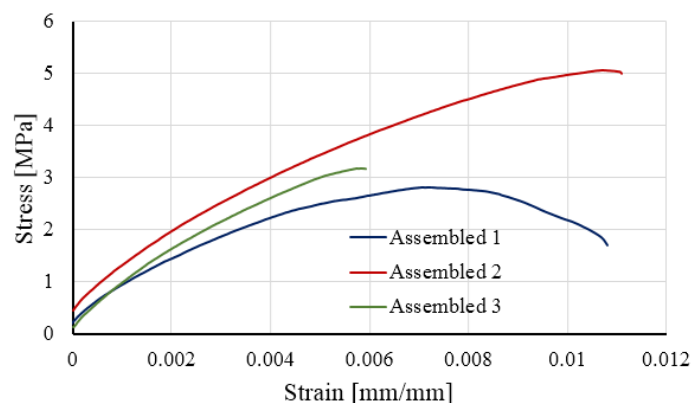
**Figure 6.** Test specimens of the VeroWhitePlus FullCure 835 material after being required for traction.

### 3. The results obtained

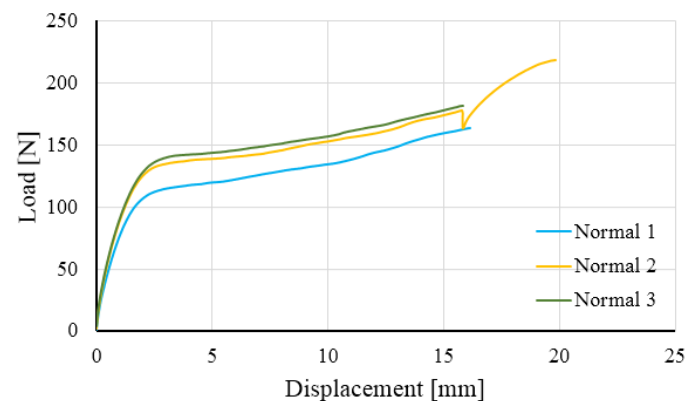
The following graphs show the results obtained from the traction tests of the two types of specimens (whole - plain and assembled - joined). The figures below were organized as follows: figure 7 – Stress/strain curves for the plain (normal) specimens; figure 8 – Stress/strain curves for the joined (assembled) specimens ; figure 9 – Load/displacement curves for the plain (normal) specimens ; figure 10 – Load/displacement curves for the joined (assembled) specimens.



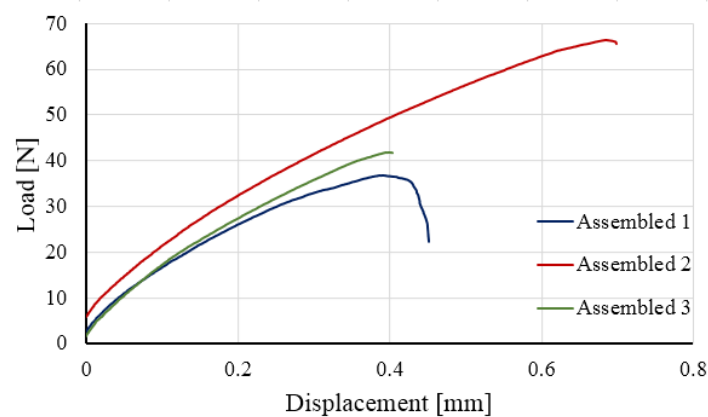
**Figure 7.** Stress/strain curves for the plain (normal) specimens of the VeroWhitePlus FullCure 835 material after being required for traction.



**Figure 8.** Stress/strain curves for the joined (assembled) specimens of the VeroWhitePlus FullCure 835 material after being required for traction.

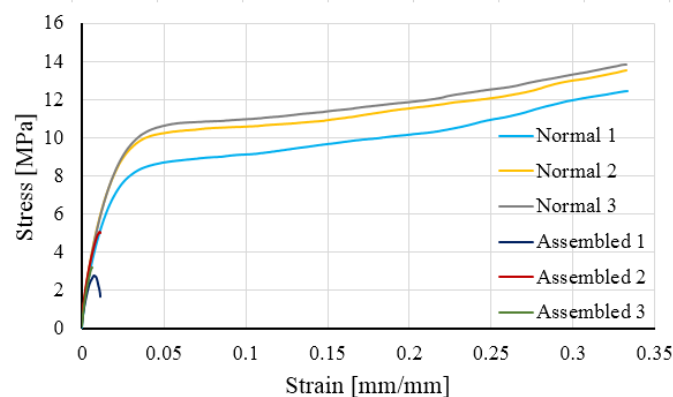


**Figure 9.** Load/displacement curves for the plain (normal) specimens of the VeroWhitePlus FullCure 835 material after being required for traction.

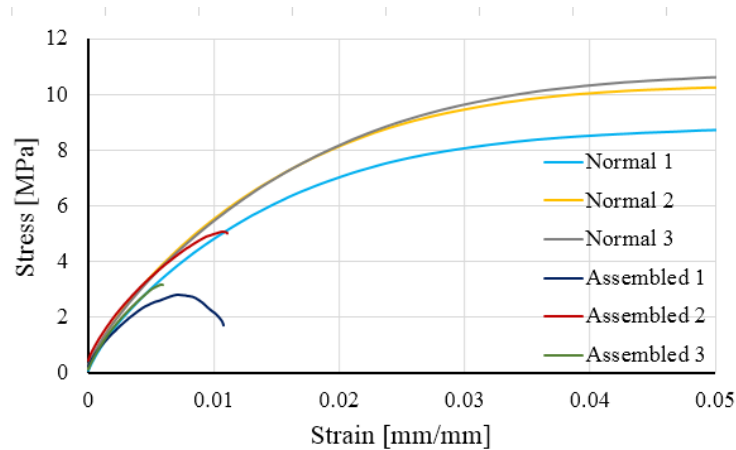


**Figure 10.** Load/displacement curves for the joined (assembled) specimens of the VeroWhitePlus FullCure 835 material after being required for traction.

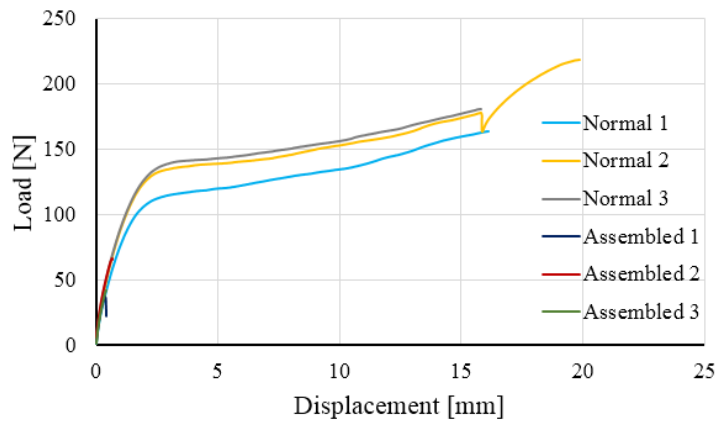
The following figures show the superimposed curves for plain and joined specimens in order to better see the difference between them. So we have the following figures: figure 11 – Stress/strain curves for the plain (normal) and joined (assembled) at scale 1; figure 12 – Stress/strain curves for the plain (normal) and joined (assembled) specimens at scale 2; figure 13 – Load/displacement curves for the plain (normal) and joined (assembled) specimens at scale 1; figure 14 – Load/displacement curves for the plain (normal) and joined (assembled) specimens at scale 2.



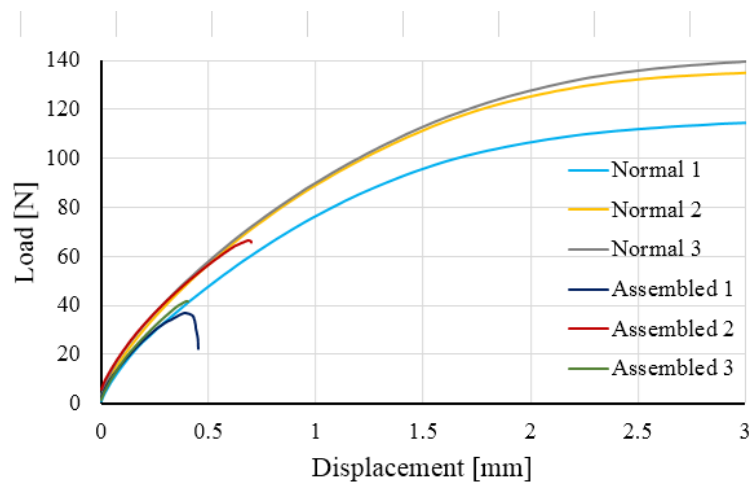
**Figure 11.** Stress/strain curves for the plain (normal) and joined (assembled) specimens of the VeroWhitePlus FullCure 835 material after being required for traction (scale 1).



**Figure 12.** Stress/strain curves for the plain (normal) and joined (assembled) specimens of the VeroWhitePlus FullCure 835 material after being required for traction (scale 2).



**Figure 13.** Load/displacement curves for the plain (normal) and joined (assembled) specimens of the VeroWhitePlus FullCure 835 material after being required for traction (scale 1).



**Figure 14.** Load/displacement curves for the plain (normal) and joined (assembled) specimens of the VeroWhitePlus FullCure 835 material after being required for traction (scale 2).

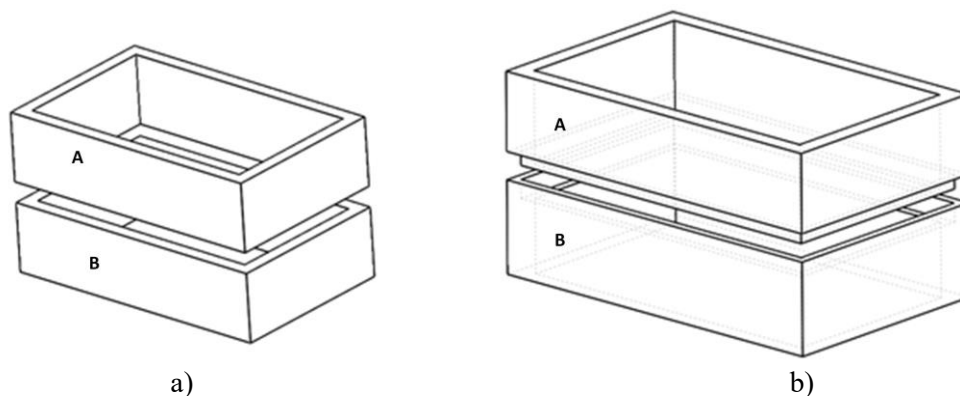
Young's modulus and tensile strength in [MPa] are shown in table 4.

**Table 4.** Young's modulus and tensile strength for plain and joined specimens.

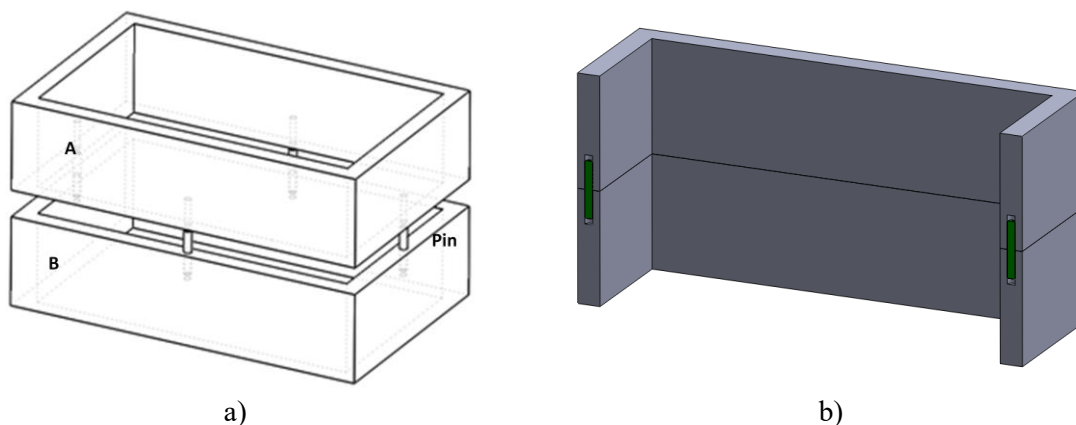
Young's Modulus strength [MPa]	Values [MPa]	Average [MPa]	St. Dev. [%]
Specimen 1	655	673	3.26
Specimen 1	697		
Specimen 1	666		
Joined 4	513	608	13.51
Joined 5	657		
Joined 6	654		
Tensile strength [MPa]	Values [MPa]	Average [MPa]	St. Dev. [%]
Specimen 1	12.47	14.31	14.87
Specimen 1	16.64		
Specimen 1	13.81		
Joined 4	2.81	3.68	32.74
Joined 5	5.06		
Joined 6	3.18		

#### 4. Design considerations

In Rapid Prototyping issues, the need for component parts assembling is often encountered. We can bind two pieces to get an assembly in a very simple way, by putting the parts together, as is shown in figure 15(a). Another more advantageous solution is the use of a negative-positive geometric shape. This is shown in figure 15(b).



**Figure 15.** Bonding assembly of two pieces A and B: a) Placing the parts head to head; b) Additional joining of the parts in positive-negative form.



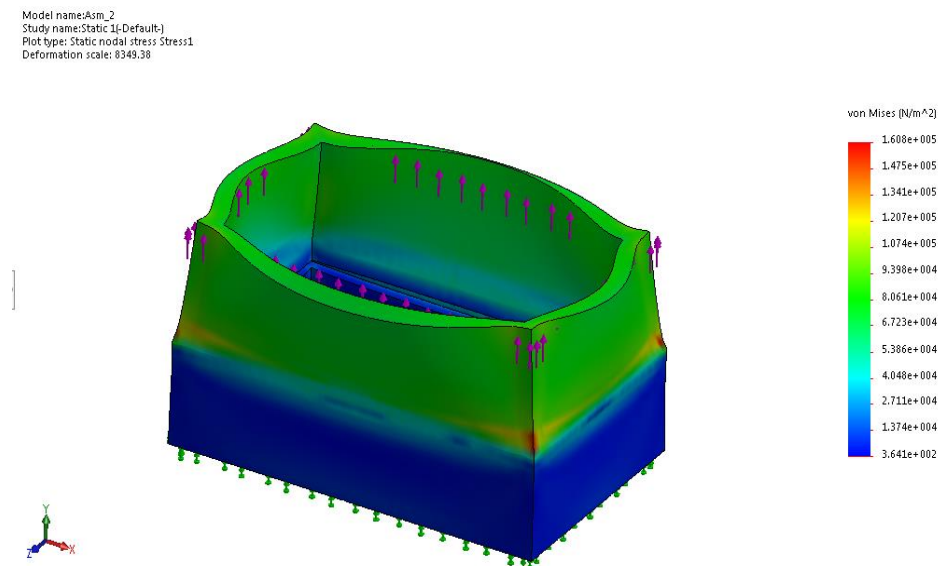
**Figure 16.** a) Assembly by gluing two pieces A and B by means of an insertion pin. b) Cross Section through the middle of the assemble.



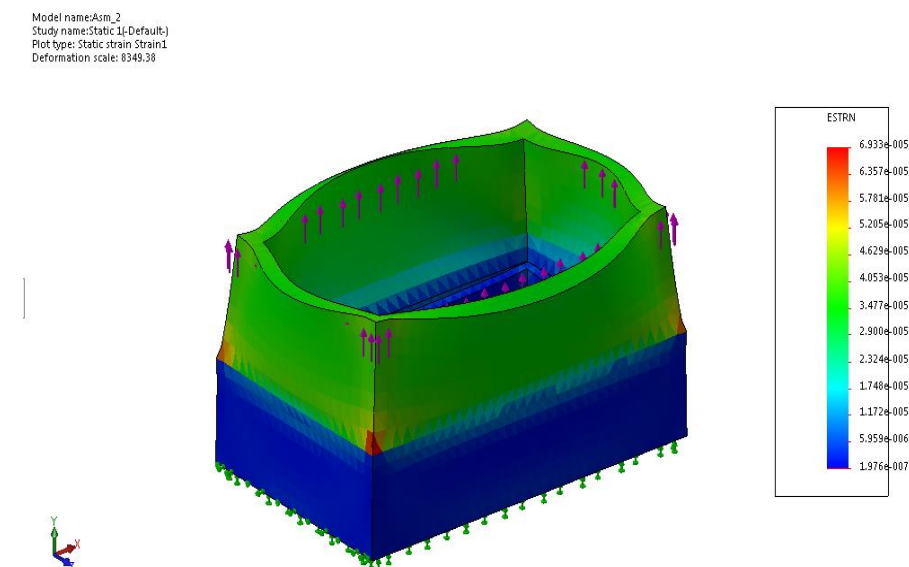
The assembly of two pieces A and B by means of an insertion pin is shown in Figure 16. Although most fast prototyping applications use special software for splitting the STL file, it is recommended that the massive parts be split into CAD system. In this way, the subsequent assembling of the parts is controlled, the final assembly is assured and the geometrical tolerances are respected.

CAD systems can section the piece by plane, after a curve, in the form of saw teeth (trapezoidal shape), circular shape, or any other geometric shape defined by the user. Although there are these different possibilities, simple geometric shapes are used in practice because otherwise the parts are difficult to assemble and solder.

A simulation of the behavior of some cyanoacrylate-bonded pieces is shown in figures 17-19 and 20. Figures 17 and 18 show the behavior of the assembly shown in figure 15, whereas figures 19 and 20 show the assembly of the parts of figure 16 bonded with cyanoacrylate. It should be noted that Pin pieces were considered to be made of plain carbon steel. The base of the assembly is considered to be fixed (piece B) and the top surface of the part A is applied at the traction with the force  $F = 20\text{N}$ .

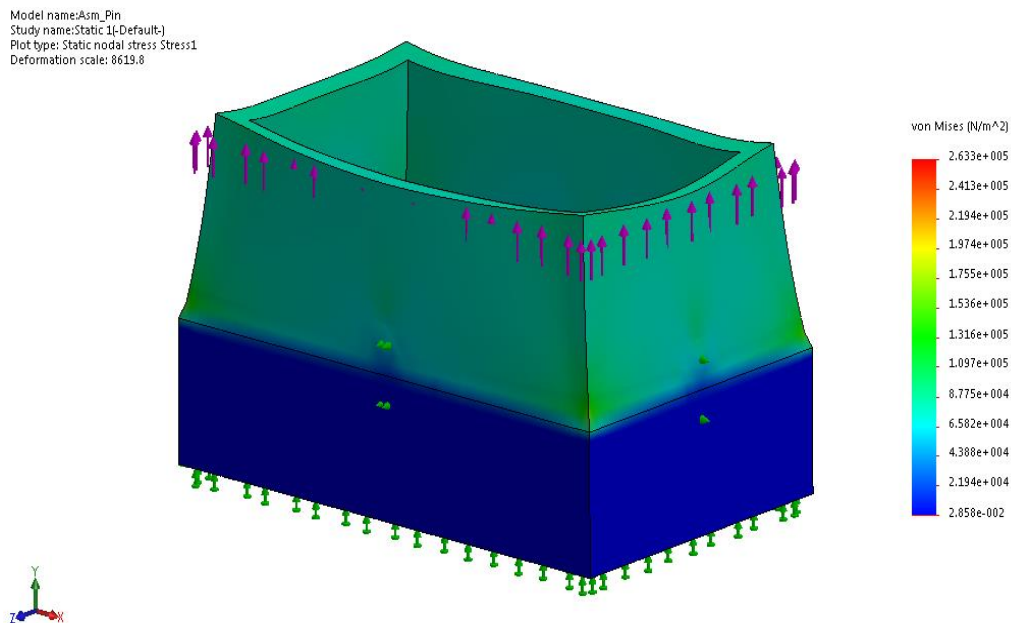


**Figure 17.** The von Mises graphic representation for the bonded assembly from figure 15(b).

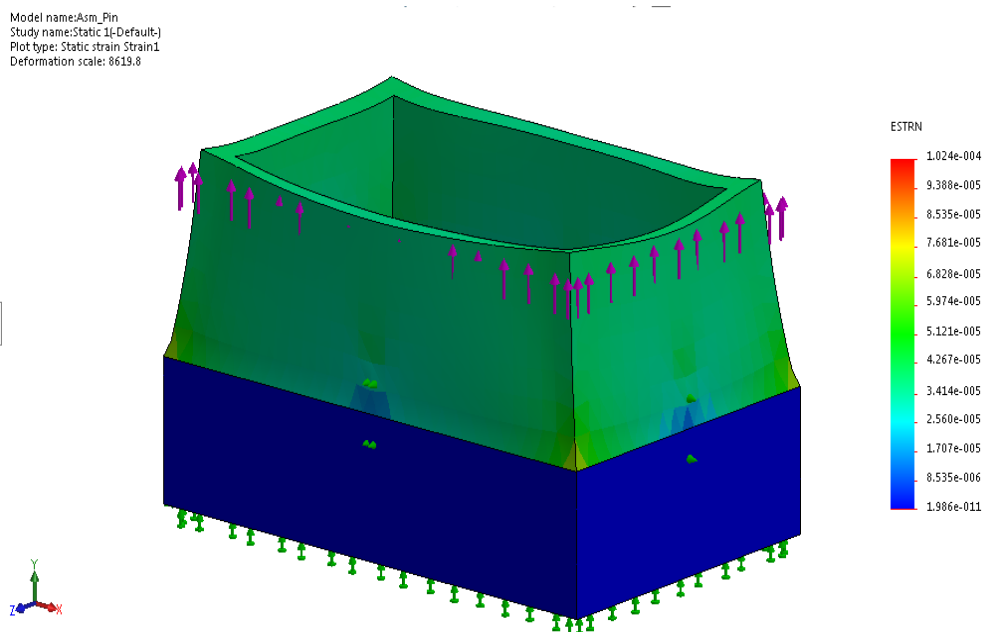


**Figure 18.** Strain graphic representation for the bonded assembly from figure 15(b).

In the SolidWorks Simulation Module, the type of bonded-rigid contact was considered for joining parts. As can be seen, the best behavior is the fitting of the parts that conform to the type of assembly in figure 16, with insertion pins. The insertion pin stiffens the pieces, places them one against the other, ensuring assembly precision and increases assembly performance by up to 300%.



**Figure 19.** The von Mises graphic representation for the bonded assembly from figure 16.



**Figure 20.** Strain graphic representation for the bonded assembly from figure 16.

Although it is more difficult to engineer the pins, this can be provided on the piece from the design stage in the CAD system. Standardized pins, preferably metallic, can also be used. There is also the possibility of making the holes later, after finishing 3D printing. This is more difficult and CNC equipment is needed.

## 5. Conclusions

In the paper a number of test specimens were made from VeroWhitePlus FullCure 835 material on a 3D ObJet24 printer. These specimens were tested for traction. It has been found that the material used in the current prototyping has different mechanical properties from those provided by the manufacturer. Another direction of research was the one in which specimens of the same material were made, which were glued with adhesives. These specimens had a reduced mechanical behavior compared to whole specimens (of the same material) by 388% lower.

Also in the paper some constructive solutions were presented regarding the joining geometry of the parts to be glued with adhesives.

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